

# Post-release habitat utilisation by *Francolinus bicalcaratus ayesha*, a critically endangered subspecies endemic to Morocco: implications for optimising future release programmes

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## Summary

Characterising the habitat use of released captive-bred birds is required to help optimise future avian reintroduction programmes. The critically endangered Double-spurred Francolin *Francolinus bicalcaratus ayesha* is endemic to north-west Morocco, where it inhabits forests of cork oak *Quercus suber*. To improve the viability of this threatened population, 300 captive-bred francolins were released into a game reserve, and post-release monitoring was conducted. This study aimed to identify habitat variables determining the habitat selection of the Double-spurred Francolin. Auditory detection was used during transect surveys of calling males to locate birds and their habitat occupation. Comparison of occupied and random plots showed that this bird is found mostly in flat topography with high cover of shrubs and dense cork oak trees, and close to the release site and water points. Conservation of Double-spurred Francolin depends on the choice of the release point within the cork oak forest, which should be in proximity to suitable cover of cork oak trees, shrubs and water points. Such choices would allow a rapid adaptation to prevailing conditions within release sites. Further multi-scale studies are needed to improve our understanding of the effects of ecological factors on the processes of habitat selection by this endemic subspecies.

## Introduction

Reintroductions, defined as attempts to establish a species in areas within its historical range where it has gone extinct, have become an accepted intervention in conservation (Seddon *et al.* 2007, Armstrong and Seddon 2008). Such programmes are often accomplished via the release of captive-bred individuals (IUCN 1998, Moorhouse *et al.* 2009, Bernardo *et al.* 2011) and post-release monitoring is necessary to confirm the validity of reintroduction as a cost-effective tool. Such monitoring can provide (1) information to assess the success of the release operation (IUCN 1998); (2) unique opportunities to clarify the species' niche requirements because they are likely to colonise the most suitable habitats first (Hirzel *et al.* 2004); and (3) fill gaps in knowledge (population biology, community ecology and conservation) of the species involved (Burnside *et al.* 2012).

The Double-spurred Francolin *Francolinus bicalcaratus* (Linnaeus 1766) is found in tropical West Africa and also in Morocco where an isolated subpopulation occurs as a local resident (Thévenot *et al.* 2003). *Francolinus bicalcaratus ayesha* is a subspecies endemic to Morocco. While *Francolinus bicalcaratus* has a conservation status of 'Least Concern' in the IUCN Red List (BirdLife International 2012, IUCN 2012), the Moroccan subspecies *ayesha* is reported as 'Critically Endangered' by Thévenot *et al.* (2003), McGowan *et al.* (1995) and El Agbani *et al.* (2011).

Currently, this subspecies occurs in the hinterland of Rabat-Casablanca in localities near Sidi Yahia des Zaër, Sidi Bettache and Ben-Slimane (Thévenot *et al.* 2003). However, it seems to have vanished from Souss (south-west Morocco) where it was common in the early 1920s and for which the most recent record was of 1–2 birds in 1987 (Thévenot *et al.* 2003). Its diet consists mainly of grains, seeds, berries and insects (Alaoui 2001). The population of *F. b. ayesha* has been reduced due to hunting and habitat destruction (Thévenot *et al.* 2003). Given this situation, the reestablishment of a viable breeding population is desired to restore its status. Consequently, as part of its strategic efforts to strengthen wild populations, Morocco's High Commission for Water, Forests and Desertification Control, in collaboration with the Royal Moroccan Federation of Hunting and the Captive Breeding Centre 'Domaine la Gazelle-Gibiers' has carried out a Double-spurred Francolin reintroduction programme.

Studying the habitat use of released animals can provide valuable insights to their responses in a new environment (Attum *et al.* 2011). This refers to the way in which an individual or species uses habitats to meet its survival needs (Block and Brennan 1993). This kind of study is also the most effective way to assess the ecological requirements of a species and to set management guidelines to assist in conservation of populations. Indeed, knowing habitat factors is an important step in the development of effective conservation strategies, particularly for endangered species (Conway and Martin 1993, Pasinelli 2000).

In Morocco, the habitat preferences of the Double-spurred Francolin are poorly known. Historically, a variety of habitats are reported to have been occupied by the subspecies *ayesha* (De la Perche 1992, Thévenot *et al.* 2003), among them, dense *matorral* (thickets) of wild olive *Olea europaea* and lentisc *Pistacia lentiscus*, open woodlands of thuja *Tetraclinis articulata*, and holm and cork oak *Quercus ilex* and *Q. suber*, but no clear pattern has emerged. Moreover, there is a complete lack of quantitative data relating to the habitats used by this 'Critically Endangered' subspecies.

We therefore studied data from a north-west Moroccan woodland, known to have supported a wild Double-spurred Francolin population in the past. Occupied/random data were recorded during planned surveys, as these are clearly preferable to occupied-only data in habitat modelling studies aimed at delineating niche boundaries (Franklin 2009).

Since habitat quality at a release site is recognised as being critical to the success of a species reintroduction program (Bennett *et al.* 2012), our major aim was to identify and quantify those characteristics of forest structure associated with the habitats chosen by *F. b. ayesha*. In this way we sought to provide reliable recommendations for future reintroductions adequate to meet the conservation needs of the subspecies. We anticipate that, in future, the results of this investigation will serve as an invaluable basis for conservation and management of this critically endangered subspecies.

We generated two related hypotheses: (1) that the Double-spurred Francolin will use forest areas with a high density of cork oak *Quercus suber* and a high shrub cover, and (2) that released birds will remain around the release point provided that the habitat is suitable; i.e. the habitat used both where a bird was released and on its habitat requirements.

## Methods

### *Study area*

Double-spurred Francolins were reintroduced and monitored at a game reserve at Sidi Allal Al Bahraoui (SABGR) (34°00'52"N, 6°28'18"W; Figure 1), which is located within the Ma'amora forest, Morocco. This forest is classified as a Biological and Ecological Interest Site by the Moroccan Protected Areas Study (AEFCS 1996). SABGR is a fenced area of about 493 ha. It is situated near the city of Sidi Allal Al Bahraoui, at 210 m asl, in the canton C of Ma'amora where annual precipitation averages 450 mm, and monthly temperatures vary from 12°C (January) to 25°C (July–August). This region is characterised by hot summers and mild winters (a semi-arid bioclimate). The study site is managed and livestock, such as sheep that are common in the region, are not permitted.

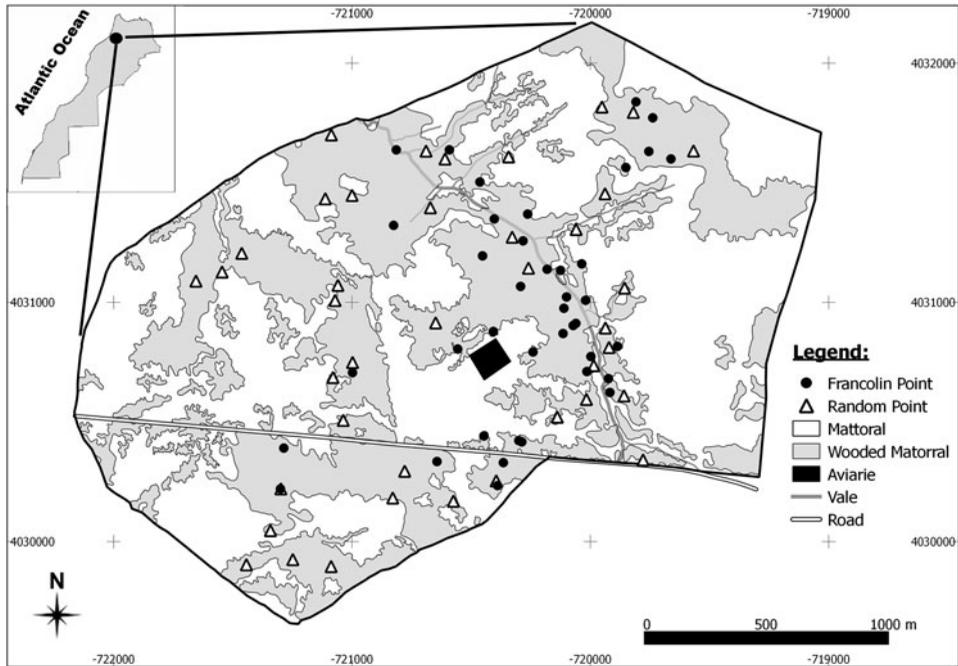


Figure 1. Map showing the location of the game reserve of Sidi Allal Al Bahraoui (SABGR) in north-west Morocco. Black points represent the location of francolins and white delta points represent the location of random points in the wooded matorral.

The vegetation of this part of Ma'amora is characterised by Araceae, Arecaceae, Cistaceae, Fabaceae, Fagaceae and Lamiaceae. The tree layer consists solely of cork oak and the shrub layer is dominated by needle-leaved broom *Teline linifolia*, Mediterranean dwarf palm *Chamaerops humilis*, sage-leak rock rose *Cistus salvifolius* and Spanish lavender *Lavandula stoechas*. The forest landscape is dominated by two habitats: (1) *matorral* (269 ha) and (2) wooded *matorral* (224 ha), which is characterised by cork oak in association with the shrub species mentioned above.

Game management in the study area is aimed mainly at Double-spurred Francolin conservation. The Royal Moroccan Federation of Hunting has set up forest trails, in which water points have been established as well as food supplements mostly composed of bread wheat *Triticum aestivum*.

### Release and population source

As stipulated in IUCN guidelines (1998), the SABGR was selected as a suitable site for Double-spurred Francolin reintroduction because: (1) there were no longer any Double-spurred Francolins in the Ma'amora forest (Thévenot 1991, Cherkaoui *et al.* 2007, 2009); (2) it is within the historic range of the species (Thévenot *et al.* 2003); and (3) it contains suitable habitats for the species (De la Perche 1992, Thévenot *et al.* 2003). It is known that the success of such reintroduction programmes is often dependent upon the suitability of habitats in the immediate area of the release site (Ewen and Armstrong 2007, Bennett *et al.* 2013).

Altogether 300 Double-spurred Francolins were released at SABGR. They came from the livestock area, called "Domaine la Gazelle-Gibiers" (DGG). The centre managers have been authorised to collect eggs from a relict natural population at Ain Sferjla Royal Reserve. The eggs were incubated

and hatched at the DGG. Releases took place in early winter (November 2011). Birds were soft-released after keeping them for two weeks in a 2.5 ha acclimatisation pen at SABGR, which contained 20 aviaries of 20 x 10 m each. Water and food were provided in the aviaries. After release, the birds were provided with food and water at several points within the SABGR. The francolins were released in groups, aviary by aviary, with a time interval of one hour. All 300 francolins were subject to a health check and found to be free from parasites and other diseases.

### *Sampling design*

#### Determination of Double-spurred Francolin territories

We conducted breeding season surveys in March 2014 and as the Double-spurred Francolin is territorial (the male sings to attract the female and to defend its territory), we used the point count method enhanced by playback (Hanane and Qninba 2014). Nowadays this technique is commonly used to increase the detection of many secretive bird species (Conway *et al.* 1993, Zuberogoitia and Campos 1998, Brambilla and Rubolini 2004), such as Galliformes (Evans *et al.* 2007, Ponce-Boutin 1992, Kasprzykowski and Gołowski 2009, Jakob *et al.* 2010, 2014, Fuller *et al.* 2012). Ten permanent transects were established (1.2–1.5 km), on each of which 4–5 points were identified as being sufficiently far apart (0.2–0.3 km) to avoid double counting. Counts were conducted at these points five times during March 2014. Each survey started between dawn and 10h00. We played Double-spurred Francolin calls from a notebook via a VLC media player and two speakers (5W each). One cycle of Double-spurred Francolin male territorial calls was played for 10 s, and any response noted in the ensuing 60 s. At each point, this process was repeated three times in each cardinal direction, to locate calling males. We discovered that the released francolins almost exclusively use wooded *matorral* in the game reserve (Hanane and Qninba 2014), and therefore we decided to restrict our counting to there.

Less than half of the francolins recorded were located visually by finding a roost site or by directly observing a breeding pair. Such visual locations give the strongest indication of the core of each territory. When we heard francolin calls, often in response to playback, and we could not locate it visually, usually because of dense vegetation, we used triangulation to determine its location with the help of three observers surrounding the calling bird and taking bearings. All Double-spurred Francolin positions were geo-referenced using a portable GPS (Magellan eXplorist XL) and then reported in an Open Source GIS (Quantum GIS v1.7.3). When a male was heard, calling either without using playback or immediately after playback was first used, it was assumed that it was actively defending its territory, and thus its location was indicative of the territory core (*F. b. ayeshah* has distinct, far-carrying vocalisations). We performed point counts only in good weather conditions (not excessively hot and no wind or rain) for two reasons: (1) to make it easier to hear birds at a greater distance; (2) to facilitate collecting the most accurate localisations of birds and random points through using GPS instruments in the best conditions (Trimble GNSS Planning online tools).

#### Selection of random points

As a first step, we excluded all points at which Double-spurred Francolins were recorded. In the second step, points were selected by drawing 40 random points using the QGIS random selection tool. The random and the presence points were equal in number to give a balanced design.

#### Measurement of habitat characteristics

Forest structure was quantified either at the locations where francolins were recorded (hereafter 'Francolin points') or for random points in circular plots with an 11.3 m radius (0.04 ha). We assumed that this radius was sufficient to characterise the francolins' habitat use because (1) the

study area is well protected and is not affected by such human activities as grazing, clearing and logging, which are known to affect the habitat structure (Kie *et al.* 1996, Fimbel *et al.* 2001, Hanane 2014); (2) the minimum distance recorded between the singing Double-spurred Francolin males was 13 m, and (3) a lesser radius was used for characterising habitat selection for other francolin species such as Handsome Francolin *Francolinus nobilis* (Ssemmanda and Fuller 2005), Grey Francolin *Francolinus pondicerianus* (Kidwai *et al.* 2011, Kidwai 2013) and Black Francolin *Francolinus francolinus* (Kidwai *et al.* 2011).

We considered: 1) geomorphological variables such as altitude, (*Alt* using a GPS), slope (*%\_Slo* using a clinometer,  $\pm 0.05$  m) and distance (m) to the nearest small valley (*D\_sva*) with QGIS; 2) vegetation variables: tree cover (*%\_tree* with visual estimation), height (m) of the tallest tree (*H\_tree* using a clinometer), diameter (cm) at breast height [DBH with a measuring tape ( $\pm 0.01$  m) of the tallest tree; tree density (*D\_tree*) by counting the number of trees within the 11.3 m radius; shrub cover (*%\_mat* using Gayton (2003) method); average height (m) of the shrub (*H\_mat* using a clinometer); herbaceous cover (*%\_her* using Gayton [2003] method), and average height (m) of the herbaceous layer (*H\_her* using a clinometer); and 3) variables related to the only man-made structures present at SABGR (release enclosures, tracks and water points) as closest distance (m) to the release site (*D\_rea*); distance (m) to the closest track (*D\_tra*), and distance (m) to the closest water point (*D\_wat*), through the application of Geographic Information Systems (QGIS, v1.7.3) to measure distances. Climatic factors were not taken into account due to the small study area (493 ha), which means that we assume similar values for temperature, precipitation, and humidity across the studied landscape.

### Statistical analysis

Before performing statistical analyses, we checked for normality and homogeneity of variance of all the variables. Variables that did not conform to the requirements for parametric tests were log-transformed prior to all analyses (Zar 1984, Underwood 1996, Quinn and Keough 2002). We also checked for possible correlations among variables by using Pearson's rank correlation (*r*) index. We collapsed habitat structure variables into independent vectors using Principal Component Analysis (PCA), since this allowed us to: (i) reduce the dimensionality of the set of variables to a smaller number of 'representative' and 'uncorrelated' variables ( $n = 14$ ); (ii) investigate multicollinearity; and (iii) describe dominant ecological gradients (Legendre and Legendre 1998). For each PCA, a varimax normalised rotation was applied to the set of principal components with eigenvalues  $> 1.0$ , to obtain simpler and more interpretable gradients (Legendre and Legendre 1998). We interpreted the biological meaning of the principal components, which explain the greatest amount of combined variation within the habitat structure data, by examining the component loadings of each variable (McGarigal *et al.* 2000).

After this first stage of analysis, we turned to modelling the occupancy probability of the Double-spurred Francolin as a function of the orthogonal predictor factors of habitat structure using the Generalised Linear Model (GLM) with binomial error (logistic regression: presence vs. random). In order to select the best GLM models, we developed an all-inclusive design by using multi-model inference (Burnham and Anderson 2002): 31 possible combination models were tested and only the best ones (10) were reported (Table 3). For each model, Akaike Information Criteria (AICs) were calculated from the general formula  $AIC = -2(\log \text{likelihood}) + 2K$ , where *K* is the number of parameters. The model with the lowest AIC was selected as the best fitting model. We corrected AIC for small sample size ( $n = 80$ ) using AICc (Burnham and Anderson 2002).

To assess whether the residuals of the best model are normally distributed, and thus acceptable, we tested the goodness-of-fit of the best model using the Le Cessie and van Howelingen test (1991). The error rate of the best model was assessed using a receiver operating characteristic (ROC) procedure.

One of the assumptions of parametric statistics is that observations are independent of each other. This assumption is often violated with spatial data. As a result, it is important to test for and

subsequently address spatial autocorrelation in data prior to data analysis. Spatial autocorrelation was tested on the residuals of the best model in terms of AIC value of the second step. We used Moran's I correlogram with 10 lags of 100 m each. We assessed the significance of the values for each lag with a Monte-Carlo test of 999 permutations. A correlogram was significant if at least one lag resulted in  $P < 0.05$ .

All statistical analyses were performed in R 3.1.0 software (R Development Core Team 2013). We used the package "ade4" for Principal Component Analysis (Dray and Dufour 2007) and "spdep" for Moran's I autocorrelation index (Paradis *et al.* 2004). After model selection, we also used a two sample t-test to determine which of the habitat variables differed significantly ( $P < 0.05$ ) between presence and random plots.

## Results

The *t*-tests conducted on the characteristics of francolin-present and random points demonstrated that distance to the nearest small valley ( $D_{sva}$ ), shrub cover ( $\%_{mat}$ ), tree cover ( $\%_{tree}$ ), shrub height ( $H_{mat}$ ), herbaceous layer height ( $H_{her}$ ), tree density ( $D_{tree}$ ), distance to the closest point of release ( $D_{rea}$ ), distance to the closest water point ( $D_{wat}$ ) and slope ( $Slp$ ) were significantly different while altitude ( $Alt$ ), tree height ( $H_{tree}$ ), tree DBH, herbaceous cover ( $\%_{her}$ ) and distance to the closest track ( $D_{tra}$ ) were not (Table 1).

The PCA summarised the 14 original variables into five axes (PC) with eigenvalues  $> 1$ , accounting together for 76.6% of the variance in the original dataset (Table 2). The first PC ( $PC_{\text{man-made structures}}$ ) represented a gradient of increasing distance to man-made structures (water points, tracks and release site). The second PC ( $PC_{\text{tree size}}$ ) depicted a gradient of increasing height of trees with high DBH. The third PC expressed the slope ( $PC_{\text{slope}}$ ) and high herbaceous height. The fourth and fifth PC axes, respectively described gradients of increasing shrub cover ( $PC_{\text{shrub cover}}$ ) and cork oak tree density ( $PC_{\text{cork oak density}}$ ) (Table 2). They can also be interpreted as concealment factors.

These five orthogonal factors were used as independent explanatory variables in a logistic regression model to assess their significance in predicting Double-spurred Francolin occupancy probability. Thirty candidate models were obtained with these five factors. In accordance with the  $\Delta AICc$  values, the most parsimonious model of Double-spurred Francolin habitat occupancy included a GLM fit to  $PC_{\text{man-made structures}}$ ,  $PC_{\text{slope}}$ ,  $PC_{\text{shrub cover}}$  and  $PC_{\text{cork oak density}}$  (Tables 3 and 4).

Table 1. Sample means and standard errors (SE) for variables measured at Francolin and random points, at SABGR, Morocco, 2014. An asterisk (\*) indicates that data differed significantly (two-sample *t*-tests,  $P < 0.05$ ).

	Abbreviations	Francolin points ( $n = 40$ )	Random points ( $n = 40$ )	<i>P</i>
Slope (%)	<i>Slp</i>	4.38 ± 0.72	7.80 ± 0.72	0.001*
Altitude (m)	<i>Alt</i>	191.42 ± 1.54	194.24 ± 1.19	0.154
Matorral cover (%)	$\%_{mat}$	61.30 ± 3.79	36.52 ± 3.96	<0.001*
Tree cover (%)	$\%_{tree}$	58.52 ± 2.88	28.41 ± 3.38	<0.001*
Herbaceous cover (%)	$\%_{her}$	73.89 ± 3.57	80.42 ± 2.39	0.135
Shrub height (m)	<i>H<sub>mat</sub></i>	1.91 ± 0.06	1.46 ± 0.11	0.001*
Tree height (m)	<i>H<sub>tree</sub></i>	10.41 ± 0.52	9.31 ± 0.69	0.211
Herbaceous height (cm)	<i>H<sub>her</sub></i>	42.38 ± 4.06	69.95 ± 2.16	<0.001*
Diameter at breast height (m)	<i>DBH</i>	1.25 ± 0.08	1.05 ± 0.10	0.145
Tree density	<i>D<sub>tree</sub></i>	4.09 ± 0.40	2.12 ± 0.22	<0.001*
Distance to the closest water point (m)	<i>D<sub>wat</sub></i>	83.07 ± 9.28	148.80 ± 21.67	0.008*
Distance to the closest track (m)	<i>D<sub>tra</sub></i>	77.59 ± 8.62	111.23 ± 18.12	0.101
Distance to the closest point of release (m)	<i>D<sub>rea</sub></i>	488.97 ± 48.90	681.15 ± 48.69	0.007*
Distance to the closest vale (m)	<i>D<sub>sva</sub></i>	230.11 ± 43.45	499.29 ± 71.41	0.002*

Table 2. Results of the principal component analysis showing the loadings of the habitat variables within each of the principal components.

Variables	Components				
	PC <sub>man-made structures</sub>	PC <sub>Cork oak size</sub>	PC <sub>Slope</sub>	PC <sub>Shrub cover</sub>	PC <sub>Cork oak density</sub>
<i>Slp</i>	0.006	-0.027	<b>0.836</b>	-0.013	-0.001
<i>Alt</i>	0.192	-0.152	-0.198	-0.116	<b>-0.814</b>
<i>%_mat</i>	-0.067	0.067	-0.197	<b>0.876</b>	0.092
<i>%_tree</i>	0.026	0.428	-0.368	0.426	0.459
<i>%_her</i>	0.254	-0.696	0.193	0.175	0.198
<i>H_mat</i>	-0.118	0.013	-0.002	<b>0.906</b>	0.064
<i>H_tree</i>	0.187	<b>0.829</b>	-0.04	0.132	0.312
<i>H_her</i>	0.137	-0.159	<b>0.862</b>	-0.231	0.047
<i>DBH</i>	0.059	<b>0.825</b>	-0.013	0.123	0.179
<i>D_tree</i>	0.092	0.066	-0.554	0.014	<b>0.718</b>
<i>D_wat</i>	<b>0.878</b>	0.179	0.142	0.051	-0.109
<i>D_tra</i>	<b>0.849</b>	0.077	0.102	-0.016	-0.037
<i>D_rea</i>	<b>0.715</b>	-0.12	-0.067	-0.203	0.096
<i>D_sva</i>	0.582	-0.215	-0.13	-0.122	-0.523
<i>Eigenvalue</i>	2.654	2.192	2.053	1.958	1.869
<i>% Explained variance</i>	18.955	15.654	14.664	13.986	13.347

The goodness-of-fit test indicated acceptable fit ( $z = 0.512, P = 0.108$ ). The error rate based on the ROC function was 0.16. The model explained 60% of the deviance in the Double-spurred Francolin occupancy and 61% of their variance.

In addition, we did not find evidence of spatial autocorrelation in model residuals between plots. The correlogram of residuals from the top AICc ranked GLM shows no significant spatial autocorrelation (Figure 2), suggesting that the results of this non-spatial GLM model were not biased by possible spatial covariance in the data.

Francolin occupancy probabilities were negatively related to PC<sub>man-made structures</sub> and PC<sub>slope</sub> (Figure 3a,b) and positively related to PC<sub>shrub cover</sub> and PC<sub>cork oak density</sub> (Figure 3c,d). These results are consistent with those of student's t-tests ( $\alpha = 0.05$ ) (Table 1).

### Discussion

The aim of the study in SABGR was to explore a relatively wide spectrum of environmental factors and identify variables responsible for habitat occupation by Double-spurred Francolin in a

Table 3. Models with the number of parameters used (k), the Akaike information criterion for small samples size (AICc), the difference between each selected model and the best model ( $\Delta AICc$ ), and the Akaike weight (AICwi). Only the 10 best models are shown (out of 31 examined).

	K	AICc	$\Delta AICc$	AIC <sub>wi</sub>
PC <sub>man-made structures</sub> + PC <sub>Slope</sub> + PC <sub>Shrub cover</sub> + PC <sub>Cork oak density</sub>	5	46.082	0	0.597
PC <sub>man-mad structures</sub> + PC <sub>Cork oak size</sub> + PC <sub>Slope</sub> + PC <sub>Shrub cover</sub> + PC <sub>Cork oak density</sub>	6	47.13	1.048	0.354
PC <sub>man-mad structures</sub> + PC <sub>Cork oak size</sub> + PC <sub>Slope</sub> + PC <sub>Shrub cover</sub>	5	52.22	6.138	0.028
PC <sub>man-mad structures</sub> + PC <sub>Slope</sub> + PC <sub>Shrub cover</sub>	4	53.973	7.891	0.012
PC <sub>Slope</sub> + PC <sub>Shrub cover</sub> + PC <sub>Cork oak density</sub>	4	55.732	9.65	0.005
PC <sub>Cork oak size</sub> + PC <sub>Slope</sub> + PC <sub>Shrub cover</sub> + PC <sub>Cork oak density</sub>	5	55.832	10.75	0.005
PC <sub>Cork oak size</sub> + PC <sub>Slope</sub> + PC <sub>Shrub cover</sub>	4	61.123	15.041	0.000
PC <sub>Slope</sub> + PC <sub>Shrub cover</sub>	3	62.897	16.815	0.000
PC <sub>man-mad structures</sub> + PC <sub>Cork oak size</sub> + PC <sub>Slope</sub> + PC <sub>Cork oak density</sub>	5	65.229	19.147	0.000
PC <sub>man-mad structures</sub> + PC <sub>Slope</sub> + PC <sub>Cork oak density</sub>	4	65.476	19.394	0.000

Table 4. Parameters and standard errors (SE) of the GLMs to explain Double-spurred Francolin occupancy probability using habitat  $PC_{\text{man-made structures}}$ ,  $PC_{\text{slope}}$ ,  $PC_{\text{shrub cover}}$  and  $PC_{\text{cork oak density}}$  as predictors.

	Estimate $\pm$ SE	z value	Pr(> z )
Intercept	-0.282 $\pm$ 0.49	-0.581	0.561
$PC_{\text{man-made structures}}$	-1.669 $\pm$ 0.69	-2.41	0.015
$PC_{\text{slope}}$	-2.259 $\pm$ 0.61	-3.698	<0.001
$PC_{\text{shrub cover}}$	2.416 $\pm$ 0.81	2.976	0.003
$PC_{\text{cork oak density}}$	1.461 $\pm$ 0.60	2.444	0.015

sample of the cork oak forest of north-west Morocco. Through this work, we have been able to present the most detailed data available to date on the habitat use of Double-spurred Francolins in Morocco.

As expected, reintroduced, captive-bred Double-spurred Francolins showed a preference for topographically flatter land (a gentle slope < 15%), a dense and high shrub layer (respectively 61% and 2.53 m), dense cork oak trees (up to 12 trees within 0.04 ha), and a proximity to man-made structures especially water points and the release point (aviaries). This supports previous observations that Double-spurred Francolins are associated with densely vegetated valleys (Thévenot *et al.* 2003) and with cork oak forest with dense undergrowth (Alaoui 2001). We also established that the predicted distribution of the subspecies is unrelated with the size of cork oak trees. This shows that the cover of both cork oak trees and shrubs is crucial for this galliform subspecies in this protected area. This is not surprising to the extent that vegetation cover is known to be very useful to the birds as it functions as both a refuge for prey and as concealment from predators (Carrascal and Alonso 2006, Rantanen *et al.* 2010). Both ground and avian predators are common throughout the Double-spurred Francolin's range in Morocco and this

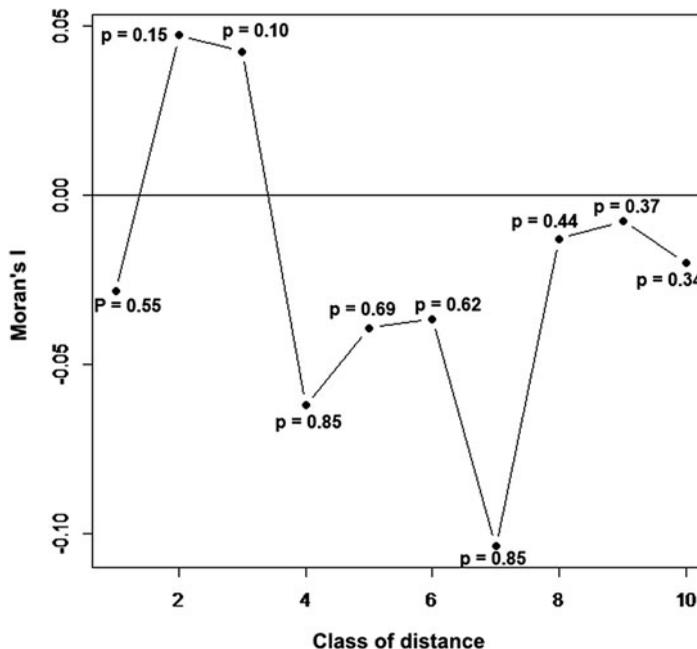


Figure 2. Correlogram of the residuals of GLM model of predicted occupancy probability as function of geomorphological variables, vegetation structure, and human activities.

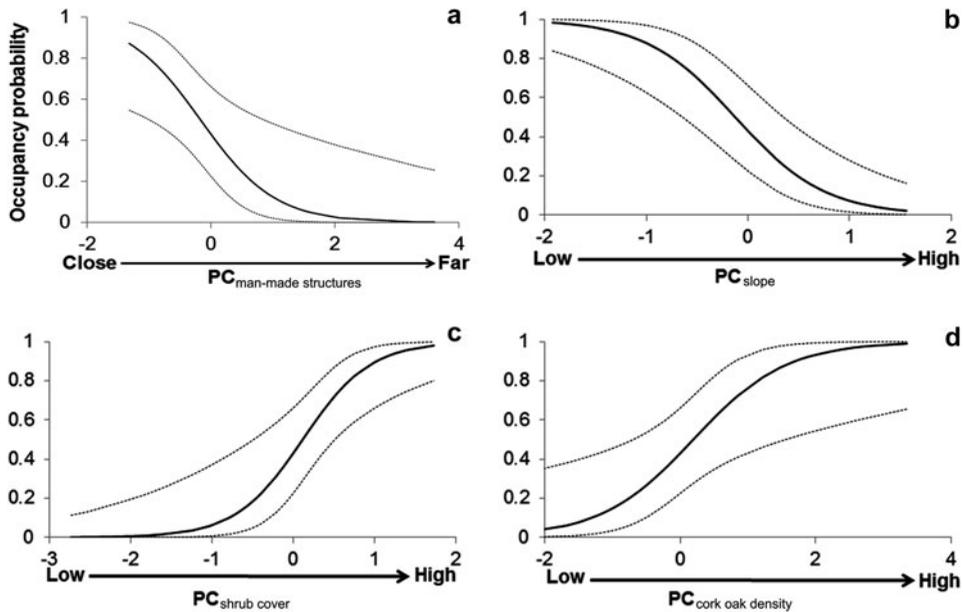


Figure 3. Occupancy probability of Double-spurred Francolins according to man-made structures (a), slope (b), shrub cover (c) and cork oak density (d) at SABGR, north-west Morocco, 2014.

forces them to remain hidden in dense vegetation to minimise the predation risk. It is worth noting that in Benin, for instance, Double-spurred Francolins use similar vegetation cover (51–90%) and shrub-layer height (1.0–2.7 m) (Codjia *et al.* 2003). Other francolin species, such as Redwing Francolin *Francolinus levaillantii* (Jansen *et al.* 2001) and Grey Francolin (Hussain *et al.* 2009) also use similar habitat. In a study of the ecology of Black Francolin on the Iranian plain of Sistan, Heidari *et al.* (2009) highlight the effect of a reduction of vegetation cover in leading to a decrease in the species' population size and distribution. It is however well known that to some extent increasing vegetative cover leads to increased thermal problems (Trautman 1982, Gatti *et al.* 1989, Gabbert *et al.* 1999, Novoa *et al.* 2006) as well as increasing predation risk by mammals (Meriggi *et al.* 1991, Tapper *et al.* 1996). Conversely, decreased vegetative cover increases avian predation, and reduces the camouflaging values and thermal protection of the habitat (Subramanian *et al.* 2002).

At SABGR, Double-spurred Francolins occupied the wooded *matorral* (with the vegetation characteristics mentioned above) near places where water was available and the release point. Indeed, the majority of francolin locations were within 100 m (90% of birds) of water points and 600 m from the release point (80%). In fact, it is recognised that bird populations are likely to be more affected at short distances from man-made structures (Madsen 1985, Benítez-López *et al.* 2010). So, why do Double-spurred Francolins in SABGR occupy wooded *matorral* located close to man-made structures? This pattern is undoubtedly related to water points, which are most often located beside paths where supplementary food left by humans can sometimes be found as wells. An alternative explanation could be that wooded *matorral* close to man-made structures is used as a refuge, which can be reached quickly once a threat is detected. This hypothesis is consistent with Martin (1993), who stated that the most common factor determining habitat use in birds under predation risk is distance to a potential refuge. Moreover, we also cannot exclude the hypothesis that francolins might have become adapted to the low frequency of human disturbance (one car passing per week) in this area. Such a low level of anthropogenic disturbance seems to be acceptable to these birds. Montgomery *et al.* (2013), in studying animal response to roads,

have also recorded habitat selection near trails (tertiary roads) under low levels of anthropogenic disturbance.

Overall, it seems that Double-spurred Francolin habitat selection would be a trade-off between the need for water and the risk of predation. Thus, by making the most of the complex habitat structure of the *matorral* forest of SABGR, the francolins may reduce the risk of predation. This is consistent with previous studies (Warfe and Barmuta 2004, Chalfoun and Martin 2009), who suggest that predation risk can be affected by the attributes of the habitat occupied by the prey.

Our results have led us to understand and become aware of the role of predation in the selection of habitat by Double-spurred Francolins. This is mainly by raptors such as Booted Eagle *Hieraaetus pennatus*, Long-legged Buzzard *Buteo rufinus*, Black Kite *Milvus migrans* and Common Kestrel *Falco tinnunculus* that occur in the same area (Cherkaoui *et al.* 2007) and to a lesser extent by mammals (e.g. common genet *Genetta genetta*, least weasel *Mustela nivalis* and red fox *Vulpes vulpes*; pers. obs.). This argument has already been proposed by Martin (1993), who stressed the implication of predation as a major factor in habitat selection and in the evolution of life history strategies of birds.

Finally, it seems that Double-spurred Francolins released at SABGR begin to adapt to local conditions as evidenced by the first recorded nests in 2014 (authors' unpubl. data). This finding should be explored by further studies.

### *Implications for future releases*

The investigation of habitat-animal associations relies on a manager's ability to understand the scale at which wildlife responds to, and interacts with, the environment (Pastor *et al.* 1996, Guarena *et al.* 2014). It is for this reason that the results of this study should be taken into account in planning future releases of the *F. b. ayesha*. In addition to the desirability of choosing a release site that is within the historical range of the subspecies (IUCN 1998), it is also important to choose a site that offers sufficient cover of cork oak trees and shrubs (e.g. needle-leaved broom). This appears to be essential in helping to protect Double-spurred Francolins from both aerial and terrestrial predators. Setting up water points and food supplements are also key prerequisites for successful release programs and conservation (Whittingham and Evans 2004). According to our results, both water points and the release site should be near or within suitable wooded *matorral*. Such conservation prescriptions would enable the birds to adapt rapidly to prevailing conditions within release sites.

To our knowledge, this is the first study that highlights the association of Double-spurred Francolins with water sources and gentle slopes. It will therefore be interesting to continue monitoring the Double-spurred Francolins at SABGR, especially to discover more about their ecology and population dynamics. Further multi-scale studies will also be valuable in improving our understanding of the effects of biotic factors (especially predation) on the processes of habitat selection. As suggested by Winnard *et al.* (2013) knowledge of habitat suitability thresholds at predator-free locations will also be important for selecting appropriate reintroduction sites in the future. Finally, in view of the fact that francolins have already begun to nest in SABGR, we believe it is important to continue our work in order to enhance our knowledge on habitat use, nest habitat selection, productivity and survival of Double-spurred Francolin.

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## References

- AEFCS (1996) Plan Directeur des Aires Protégées du Maroc. Administration des Eaux et Forêts et de la Conservation des Sols/BCEOM/SECA/ISR/EPHE. (Unpublished report).
- Alaoui, M. Y. (2001) Double-spurred Francolin (*Francolinus bicalcaratus*) at Morocco: Biology, ecology, present status, measures for preservation and future prospects for the species. Pp. 84–89 in N. Kassinis and P. Panayides, eds. *Proceedings of the symposium on the status, management and conservation of the species Alektoris, Black Francolin, Thrush, Quail and Turtle Dove in the Mediterranean Region*. Nicosia, Cyprus: The Cypriot Game Fund Service, Ministry of the Interior.
- Armstrong, D. P. and Seddon, P. J. (2008) Directions in reintroduction biology. *Trends Ecol. Evol.* 23: 20–25.
- Attum, O., Otoum, M., Amr, Z. and Tietjen, B. (2011) Movement patterns and habitat use of soft-released translocated spur thighed tortoises, *Testudo graeca*. *Eur. J. Wildl. Res.* 57: 251–258.
- Benítez-López, A., Alkemade, R. and Verweij, P. A. (2010) The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. *Biol. Conserv.* 143: 1307–1316.
- Bennett, V. A., Doerr, V. A. J., Doerr, E. D., Manning, A. D., Lindenmayer, D. B. and Yoon, H.-J. (2012) Habitat selection and post-release movement of reintroduced Brown Treecreeper individuals in restored temperate woodland. *PLoS ONE* 7(12): e50612.
- Bennett, V. A., Doerr, V. A. J., Doerr, E. D., Manning, A. D., Lindenmayer, D. B. and Yoon, H.-J. (2013) Habitat selection and behaviour of a reintroduced passerine: Linking experimental restoration, behaviour and habitat ecology. *PLoS ONE* 8(1): e54539.
- Bernardo, C. S. S., Lloyd, H., Olmos, F., Cancian, L. F. and Galetti, M. (2011) Using post-release monitoring data to optimize avian reintroduction programs: a 2-year case study from the Brazilian Atlantic Rainforest. *Anim. Conserv.* 14: 676–686.
- BirdLife International (2012) *Pternistis bicalcaratus*. *The IUCN Red List of Threatened Species*. Version 2014.2. <www.iucnredlist.org>.
- Block, W. M. and Brennan, L. A. (1993) The habitat concept in ornithology: Theory and applications. Pp. 35–91 in D. M. Power, ed. *Current Ornithology*. Volume 11. New York: Plenum Press.
- Brambilla, M. and Rubolini, D. (2004) Water Rail *Rallus aquaticus* breeding density and habitat preferences in northern Italy. *Ardea* 92: 111–118.
- Burnham, K. P. and Anderson, D. R. (2002) *Model selection and inference: A practical information-theoretic approach*. Second Edition. New York: Springer-Verlag.
- Burnside, R. J., Carter, I., Dawes, A., Waters, D., Lock, L., Goriup, P. and Székely, T. (2012) The UK great bustard *Otis tarda* reintroduction trial: a 5-year progress report. *Oryx* 46: 112–121.
- Carrascal, L. M. and Alonso, C. L. (2006) Habitat use under latent predation risk. A case study with wintering forest birds. *Oikos* 112: 51–62.
- Chalfoun, A. D. and Martin, T. E. (2009) Habitat structure mediates predation risk for sedentary prey: experimental tests of alternative hypotheses. *J. Anim. Ecol.* 78: 497–503.
- Cherkaoui, S. I., Dakki, M., Selmi, S., Rguibi Idrissi, H. and Thévenot, M. (2007) Les oiseaux de la subéraie de la Maamora (Maroc): Phénologie du peuplement, statut des espèces nicheuses et évolution depuis le début du vingtième siècle. *Alauda* 75: 3–20.
- Cherkaoui, I., Selmi, S., Boukhriss, J., Rguibi Idrissi, H. and Dakki, M. (2009) Factors affecting bird richness in a fragmented cork oak forest in Morocco. *Acta Oecol.* 35: 197–205.
- Codjia, J. T. C., Ékué, M. R. M. and Mensah, G. A. (2003) Ecologie du Francolin à double éperon *Francolinus bicalcaratus* dans le sud-est du Bénin. *Malimbus* 25: 77–84.
- Conway, C. J. and Martin, T. E. (1993) Habitat suitability for Williamson's Sapsuckers in mixed-conifer forests. *J. Wildl. Managet.* 57: 322–328.
- Conway, C. J., Eddleman, W. R., Anderson, S. H. and Hanebury, L. R. (1993) Seasonal changes

- in Yuma Clapper Rail vocalization rate and habitat use. *J. Wildl. Managet.* 57: 282–290.
- De la Perche, N. (1992) Moroccan Double-spurred Francolin. *Dutch Birding* 141: 10–12.
- Dray, S. and Dufour, A. B. (2007) The ade4 package: implementing the duality diagram for ecologists. *J. Stat. Software* 22: 1–20.
- El Agbani, M. A., Qninba, A., Radi, M., El Hamoumi, R., Cherkaoui, I., Himmi, O., Bouajaja, A. and Dakki, M. (2011) *Les oiseaux d'intérêt patrimonial au Maroc*. Rabat, Morocco: Groupe de Recherche et de Protection des Oiseaux du Maroc (GREPOM). Publication GREPOM no. 3).
- Evans, S. A., Redpath, S. M., Leckie, F. and Mougeot, F. (2007) Alternative methods for estimating density in an upland game bird: the red grouse *Lagopus lagopus scoticus*. *Wildl. Biol.* 13: 130–139.
- Ewen, J. G. and Armstrong, D. P. (2007) Strategic monitoring of reintroductions in ecological restoration programmes. *Ecoscience* 14: 401–409.
- Fimbel, R., Robinson, J. G. and Grajal, R. (2001) Logging-wildlife issues in the tropics: an overview. Pp. 3–9 in R. A. Fimbel, A. Grajal and J. G. Robinson, eds. *The cutting edge: Conserving wildlife in logged tropical forests*. New York: Columbia University Press.
- Franklin, J. (2009) Vegetation dynamics and exotic plant invasion following high severity crown fire in a southern California conifer forest. *Plant Ecol.* 207: 281–295.
- Fuller, R. A., Akite, P., Amuno, J. B., Fuller, C. L., Ofwono, J. M., Proaktor, G. and Ssemmanda, R. (2012) Using playback of vocalisations to survey the Nahan's francolin, a threatened African forest galliform. *Ostrich* 83: 1–6.
- Gabbert, A. E., Leif, A. P., Purvis, J. R. and Flake, L. D. (1999) Survival and habitat use by ring-necked pheasants during two disparate winters in South Dakota. *J. Wildl. Managet.* 63: 711–722.
- Gatti, R. C., Dumke, R. T. and Pils, C. M. (1989) Habitat use and movements of female ring-necked pheasants during fall and winter. *J. Wildl. Managet.* 53: 462–475.
- Guerena, K. B., Castelli, P. M., Nichols, T. C. and Williams, C. K. (2014) Spatially-explicit land use effects on nesting of Atlantic Flyway resident Canada geese in New Jersey. *Wildl. Biol.* 20: 115–121.
- Hanane, S. (2014) Effects of human disturbance on nest placement of the woodpigeon (*Columba palumbus*): a case study from the Middle Atlas, Morocco. *Integrative Zool.* 9: 349–359.
- Hanane, S. and Qninba, A. (2014) Post-release monitoring of a critically endangered galliform subspecies, *Francolinus bicalcaratus ayesha*, in Morocco: a field study using playback call counts. *Zool. Ecol.* 24: 332–338.
- Heidari, N., Arbabi, T., Noori, G. and Shahriari, A. (2009) Distribution, population, and ecology of Black Francolin *Francolinus francolinus bogdanovi* on the Sistan Plain, in relation to plant coverage and drought. *Podoces* 4: 28–36.
- Hirzel, A. H., Posse, B., Oggier, P. A., Crettendand, Y., Glenz, C. and Arlettaz, A. (2004) Ecological requirements of reintroduced species and the implications for release policy: the case of the Bearded Vulture. *J. Appl. Ecol.* 41: 1103–1116.
- Hussain, I., Nisa, A. and Khalil, S. (2009) Population biology of the Grey Francolin (*Francolinus pondicerianus*) in an agro-ecosystem of the Pothwar Plateau, Pakistan. *Chinese Birds* 3: 91–102.
- IUCN (1998) *Guidelines for reintroductions*. Gland, Switzerland, and Cambridge, UK: IUCN.
- IUCN (2012) *IUCN Red List of Threatened Species* (ver. 2012.1). Available at: <http://www.iucnredlist.org>.
- Jakob, C., Ponce-Boutin, F., Besnard, A. and Eraud, C. (2010) On the efficiency of using song playback during call count surveys of Red-legged partridges (*Alectoris rufa*). *Eur. J. Wildl. Res.* 56: 907–913.
- Jakob, C., Ponce-Boutin, F. and Besnard, A. (2014) Coping with heterogeneity to detect species on a large scale: N-mixture modeling applied to red-legged partridge abundance. *J. Wildl. Managet.* 78: 540–549.
- Jansen, R., Robinson, E. R., Little, R. M. and Crowe, T. M. (2001) Habitat constraints limit the distribution and population density of redwing francolin, *Francolinus levaillantii*, in the highland grasslands of Mpumalanga province, South Africa. *Afr. J. Ecol.* 39: 146–155.

- Kasprzykowski, Z. and Goławski, A. (2009) Does the use of playback affect the estimates of numbers of grey partridge *Perdix perdix*? *Wildl. Biol.* 15: 123–128.
- Kidwai, Z. (2013) Effect of anthropogenic factors on the abundance of Galliformes in Sariska Tiger Reserve, Rajasthan, India. *Avian Ecol. Behav.* 23: 3–13.
- Kidwai, Z., Sankar, K., Qureshi, Q. and Khan, J. A. (2011) Abundance and habitat utilisation by Galliformes in the Sariska Tiger Reserve, Rajasthan, India. *Int. J. Galliformes Conserv.* 2: 54–60.
- Kie, J. G., Baldwin, J. A. and Evans, C. J. (1996) CALHOME: a program for estimating animal home ranges. *Wildl. Soc. Bull.* 24: 342–344.
- Le Cessie, S. and van Houwelingen, J. C. (1991) A goodness of fit test for binary regression models based on smoothing methods. *Biometrics* 47: 1267–1282.
- Legendre, P. and Legendre, L. (1998) *Numerical ecology*. 2nd English edition. Amsterdam, The Netherlands: Elsevier.
- Madsen, S. J. (1985) *Habitat use by cavity-nesting birds in the Okanogan National Forest, Washington*. M.Sc. thesis. University of Washington, Seattle, Washington.
- Martin, T. E. (1993) Nest predation and nest sites. *BioScience* 43: 523–532.
- McGarigal, K., Cushman, S. A. and Stafford, S. (2000) *Multivariate statistics for wildlife and ecology research*. New York, USA: Springer Verlag.
- McGowan, P. J. K., Dowell, S. D., Carroll, J. P. and Aebischer, N. J. (1995) *Partridges, quails, francolins, snowcocks and guinea-fowl: Status survey and conservation action plan 1995–1999*. Gland, Switzerland and Cambridge, UK: IUCN.
- Meriggi, A., Montagna, D. and Zacchetti, D. (1991) Habitat use by partridges (*Perdix perdix* and *Alectoris rufa*) in an area of northern Apennines, Italy. *Boll. Zool.* 58: 85–89.
- Montgomery, R. A., Roloff, G. J. and Millsbaugh, J. J. (2013) Variation in elk response to roads by season, sex, and road type. *J. Wildl. Manag.* 77: 313–325.
- Moorhouse, T. P., Gelling, M. and Macdonald, D. W. (2009) Effects of habitat quality upon reintroduction success in water voles: evidence from a replicated experiment. *Biol. Conserv.* 142: 53–60.
- Novoa, C., Dumas, S. and Resseguier, J. (2006) Home-range size of Pyrenean grey partridges *Perdix perdix hispaniensis* during the breeding season. *Wildl. Biol.* 12: 11–18.
- Paradis, E., Claude, J. and Strimmer, K. (2004) APE: analyses of phylogenetics and evolution in R language. *Bioinformatics* 20: 289–290.
- Pasinelli, G. (2000) Oaks (*Quercus* sp.) and only oaks? Relations between habitat structure and home range size of the Middle Spotted Woodpecker (*Dendrocopos medius*). *Biol. Conserv.* 93: 227–235.
- Pastor, J., Mladenoff, D., Haila, Y., Bryant, J. and Payette, S. (1996) Biodiversity and ecosystem processes in boreal regions. Pp. 33–69 in H. A. Mooney, J. H. Cushman, E. Medina, O. E. Sala and E. D. Schulze, eds. *Functional roles of biodiversity: a global perspective*. London, UK: John Wiley.
- Ponce-Boutin, F. (1992) Protocole de suivi des populations de perdrix rouges par indice magnétophone au printemps. *Bulletin ONCFS, Paris*. (In French).
- Quinn, G. P. and Keough, M. J. (2002) *Experimental design and data analysis for biologists*. Cambridge, UK: Cambridge University Press.
- R Development Core Team (2013) *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. <http://www.R-project.org>.
- Rantanen, E. M., Buner, F., Riordan, P., Sotherton, N. and Macdonald, D. W. (2010) Habitat preferences and survival in wildlife reintroductions: an ecological trap in reintroduced grey partridges. *J. Appl. Ecol.* 47: 1357–1364.
- Seddon, P. J., Armstrong, D. P. and Maloney, R. F. (2007) Developing the science of reintroduction biology. *Conserv. Biol.* 21: 303–312.
- Ssemmanda, R. and Fuller, R. A. (2005) Assessing the status of Handsome Francolin *Francolinus nobilis* in Bwindi Impenetrable National Park, western Uganda. *Scopus* 25: 41–50.
- Subramanian, C., Sathyanarayana, M. C. and Kamarajan, K. (2002) Habitat utilization

- by grey jungle fowl (*Gallus sonneratii*) in the Forest Division, Meghamalai, Tamilnadu. Pp. 28–36 in *Proceedings of the National Symposium on Galliformes*. Tamil Nadu: A. V. C. College.
- Tapper, S. C., Potts, G. R. and Brockless, M. H., (1996) The effect of an experimental reduction in predation pressure on the breeding success and population density of grey partridges *Perdix perdix*. *J. Appl. Ecol.* 33: 965–978.
- Thévenot, M. (1991) Les oiseaux des forêts de chêne-liège du Maroc. Pp. 197–234 in C. Villemant and A. Fraval, eds. *La faune du chêne-liège*. Rabat, Morocco : Actes éditions de l'Institut Agronomique et Vétérinaire Hassan II. (In French).
- Thévenot, M., Vernon, J. D. R. and Bergier, P. (2003) *The birds of Morocco*. Peterborough, UK: British Ornithologists' Union Checklist Series: 20.
- Trautman, C. G. (1982) *History, ecology and management of the ring-necked pheasant in South Dakota*. Pierre, South Dakota: South Dakota Game, Fish and Parks Department.
- Underwood, A. J. (1996). *Experiments in ecology*. Cambridge, UK: Cambridge University Press.
- Warfe, D. M. and Barmuta, L. A. (2004) Habitat structural complexity mediates the foraging success of multiple predator species. *Oecologia* 141: 171–178.
- Whittingham, M. J. and Evans, K. L. (2004) The effects of habitat structure on predation risk of birds in agricultural landscapes. *Ibis* 146: 210–220.
- Winnard, A. L., Di Stefano, J. and Coulson, G. (2013) Habitat use of a critically-endangered species in a predator-free but degraded reserve in Australia. *Wildl. Biol.* 19: 429–438.
- Zar, J. H. (1984) *Biostatistical analysis*. Englewood Cliffs, NJ: Prentice-Hall, Inc.
- Zuberogitia, I. and Campos, L. F. (1998) Censusing owls in large areas: a comparison between methods. *Ardeola* 45: 47–53.

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